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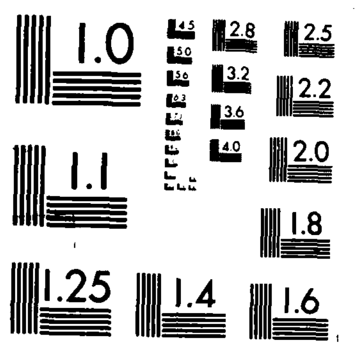
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AN EMPIRICAL SURFACE TEMPERATURE MODEL

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ABSTRACT

To help fill a critical gap in Assisted Target Recognition (ATR) capabilities, the U.S. Army Engineer Topographic Laboratories is developing an empirical surface temperature model with a few simple inputs available to the field Army, and based upon long term radiometric and meteorological measurements in several climates. It is based upon analogous climates and type-days of similar weather conditions.

INTRODUCTION

In a thermal infrared (IR) image, the camouflaging effect of background clutter creates a difficult problem. The background may be the same temperature or warmer than all, or parts, of a military target. Vehicles can successfully hide thermally in the right background, at the right time of day. Thermal infrared surface temperature models are necessary to deal with the challenge of automatic, or Assisted Target Recognition, false target discrimination and forward looking infrared (FLIR) image interpretation.

Energy budget "first-principles" models represent the current status of surface temperature prediction, but those analyses are too complex and require too much input. They require many unrealized assumptions, such as one-dimensional heat flow and laminar air flow. They require inputs, often numbering over 30 types, of complex measurements not available to the field Army, as in the models by Balick, et al. (1981). These models still utilize empirical relations to estimate critical, realistically unmeasurable values, in the manner of Geiger (1965) and Sellers (1965).

Other current models, or tactical decision aids (TDA's), like those done by Higgins (1984) and Higgins, et al. (1987) are of a very restricted type, using "snapshot data" and still have an extensive list of inputs (5 system, 5 target/background, 26 site/meteorological). I have concluded that these models are not usable outside of a carefully measured, calibrated field site, and they cannot be simplified for tactical use.

APPROACH

Our previous work indicated the great complexity of the modeling problem exhibited by the "first-principles" models, and we determined to skip ahead to an interim solution, with simplified model inputs, to fill the void of useful models.

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We decided to let the model evolve from the data, therefore, the model is empirical. The model is based upon "type-days" of relatively unique sky-cover conditions. We postulated that in a given climate, in a given season, on a given type-day, meteorological variables would be repeatable, and backgrounds would have repeatable diurnal temperature curves.

The model is being developed from meteorological, radiometric and temperature data taken around the clock for several years, at a temperate climate site in Northern Virginia, and, in cooperation with the Department of the Interior, Geological Survey, Geologic Division, Astrogeology Branch, Flagstaff, Arizona, at a semiarid site in New Mexico. Data collection in other climates is being planned.

DESCRIPTION OF THE WORK

The project entailed assembling composite or type-days of similar weather and sky cover conditions and doing a regression computation on the associated values for background temperature through the diurnal cycle.

The seven "type-days" selected for the temperate climate are listed in Table 1, and these are the model inputs.

Table 1
The Seven Type-Days

1. Clear	Dry Surface Soil
2. Clear	Wet Surface Soil
3. Partly Cloudy	Dry Surface Soil
4. Partly Cloudy	Wet Surface Soil
5. Overcast	Dry Surface Soil
6. Overcast	Wet Surface Soil
7. Overcast, Rain	Wet Surface Soil

Surface soil moisture affects surface temperature greatly and had to be addressed. We didn't expect the field Army to be measuring soil moisture, so we made the soil moisture input, "dry" or "wet," a simple observation of bare surface soil.

The backgrounds, target and temperature differences that were available at the temperate site are listed in Table 2.

Table 2
Backgrounds, Target and Temperature Differences

1. Cut Grass	Temperature
2. Bare Soil	Temperature (silty sand)
3. Uncut Grass/Weeds	Temperature
4. Gravel	Temperature
5. M114 Armored Reconn. Vehicle	Temperature
6. M114-Cut Grass	Temperature Difference
7. M114-Bare Soil	Temperature Difference
8. M114-Uncut Grass	Temperature Difference
9. M114-Gravel	Temperature Difference

The temperature differences (items 6-9) were put in so that we would have an accurate value and not have to subtract one regression curve from another to determine thermal contrasts while using the model. All temperatures used in the study are degrees Celsius. Because emissivities of backgrounds could not be measured practically, we used effective blackbody temperatures throughout, just as a tactical system would do.

In the first attempt, we subjectively sorted days and parts of days from our 33,750 records from 1984 and 1985 into the seven type-days, using a multiple plot. The plotted variables used for this sorting are shown in Table 3.

Table 3
Meteorological Variables Used to Sort Type-Days

1. Short-Wave Incoming Radiation (Swi) (0.2-2.8 um)
2. Long-Wave Incoming Radiation (Lwi) (4-50 um)
3. Air Temperature
4. Dew Point Temperature
5. Bare Soil Surface Radiometric Temperature
6. Precipitation
7. Wind Speed
8. Soil Moisture Near The Surface

Daytime periods were sorted mainly on the basis of the shape of the short-wave incoming radiation curve. Surface radiometric temperature and air temperature were also used extensively to recreate the meteorological environment.

Nighttime periods were sorted using surface radiometric temperature, air temperature, dew-point temperature and long-wave incoming radiation. A malfunctioning long-wave incoming radiation sensor created problems in sorting nighttime periods.

The observations used included 20 background temperatures, temperature contrasts and meteorological variables. All the observations for days fitting into a given type-day were placed in a separate, composite file. The files were shuffled to put the observations into chronological order, through the 24-hour diurnal cycle, by time of day (0-1). The shuffled files were separated into three parts, with a 0.2 of a day overlap, to develop polynomial regression curves for each part, since a single polynomial curve would not be suitable. Polynomial regressions were computed for each third of each 24-hour period, for each of 11 background temperatures and temperature differences for each type-day. Altogether, 231 regression curves were developed for the summer season. The plots of the three regression curves for each background, were overlaid together on a light table to find the match points. The two match points and the regression coefficients constituted a file to recreate the diurnal curve.

The partly cloudy type-days had considerable surface temperature variation because of the variability of conditions contained in this category. In this subjective method, we digitized the top and bottom envelopes from a plot of the

data. These envelopes should represent the maximum (sunlit) and minimum (shaded) conditions inherent in the partly cloudy type-day. Future refinements should subdivide this type-day category into a partly cloudy and a mostly cloudy condition.

RESULTS

A computer program takes the model inputs (see Table 4) and reads a file of match points and coefficients. The three merged polynomial regression equations are computed and the curve can be plotted. The form of the polynomial regression equations is shown in Equation 1. Six orders were used for the equations to allow for certain cases, but typical curves were third order on the ends and fourth order in the middle, to produce diurnal curves similar to real data.

$$y(x)= b_0 + b_1 x + b_2 x^2 + b_3 x^3 + \ldots + b_n x^n \qquad (1)$$

Table 4
Inputs to the USAETL Surface Temperature Model

- Season
  - Summer
  - Fall
  - Winter
  - Spring
- Sky Conditions
  - Clear
  - Partly Cloudy
  - Partly Cloudy, Upper Envelope
  - Partly Cloudy, Lower Envelope
  - Overcast
  - Overcast, Raining
- Surface Soil Moisture
  - Dry
  - Wet
- Background or Thermal Contrast
  - Cut Grass
  - Bare Soil
  - Uncut Grass/Weeds
  - Gravel
  - M114 Armored Reconnaissance Vehicle
  - M114 - Cut Grass
  - M114 - Bare Soil
  - M114 - Uncut Grass/Weeds
  - M114 - Gravel

A program that compares the predicted model curve with raw data from the data base was used to test the model using 1987 data (see Figures 1-4). Figure 1 is a bare soil background in a clear dry condition in mid June that had persisted for several days. Figure 2 is a bare soil background in a clear wet condition, 25 mm of rain having occurred the previous day. The wet ground is indicative of the previous rainfall that cleaned the air, leaving a true, clear sky.

Some clouds after midnight raised plot temperature and clouds in late morning reduced plot temperature. Figure 3 is a bare soil background in an overcast dry condition with some clouds in the early morning that lowered plot temperature by shading, Figure 4 represents a bare soil background in an overcast raining condition with light rain.

This empirical model provides a reasonable value for various background temperatures, a target temperature, and various meteorological variables for typical days. The model comes directly from the data and contains no estimates of critical factors needed to compute the model. The inputs to the model are simple, requiring no measurements. For all the simplicity of the inputs, it does a good job of temperature prediction. This model illustrates the feasibility of this empirical approach.

CONCLUSIONS

We have observed a great need for this empirical approach to fill the gap of simple, usable predictive models and to provide data to test other models. We have concluded from this effort that this is a feasible and necessary approach.

This type of data is needed in other climates, and we started data collection near Las Cruces, New Mexico, a semiarid desert, in September, 1986. In 1988, another site will be automatically collecting and transmitting data to us from Yuma, Arizona. Another desert site is envisioned in Death Valley, California, and a moist, tropical site is planned for Puerto Rico.

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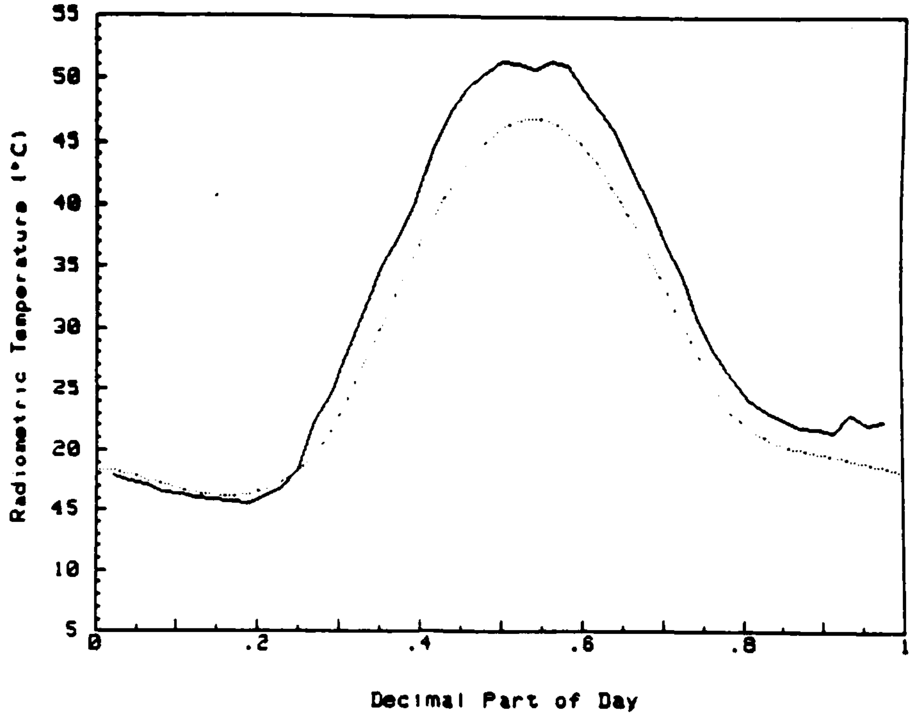

Figure 1. Measured (solid line) and predicted (dotted line) effective blackbody temperatures for bare soil on a clear dry summer day on June 19, 1987.

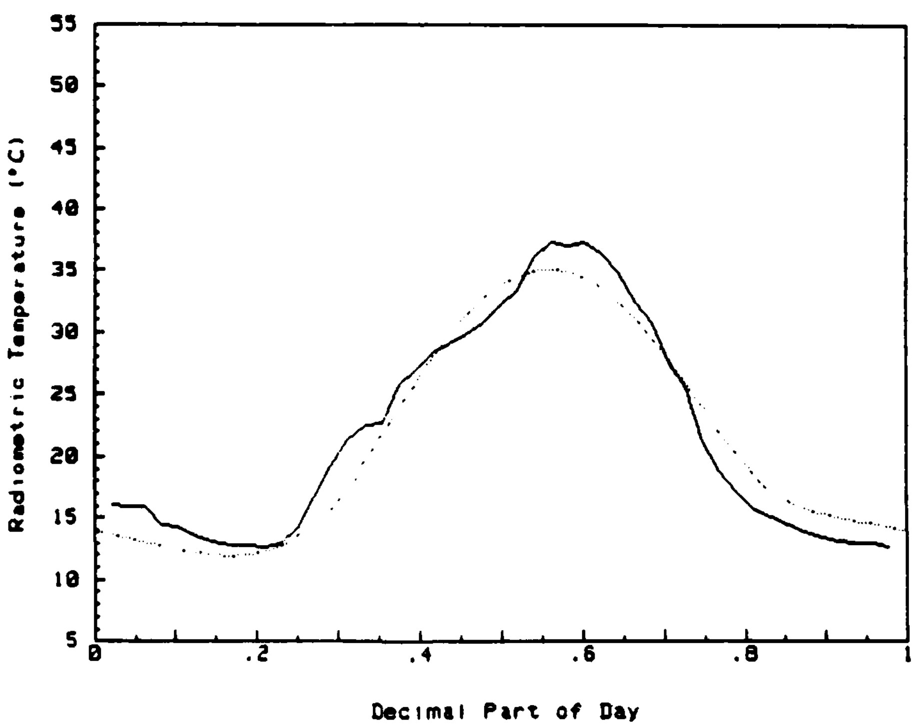

Figure 2. Measured (solid line) and predicted (dotted line) effective blackbody temperatures for bare soil on a clear wet summer day on June 5, 1987.

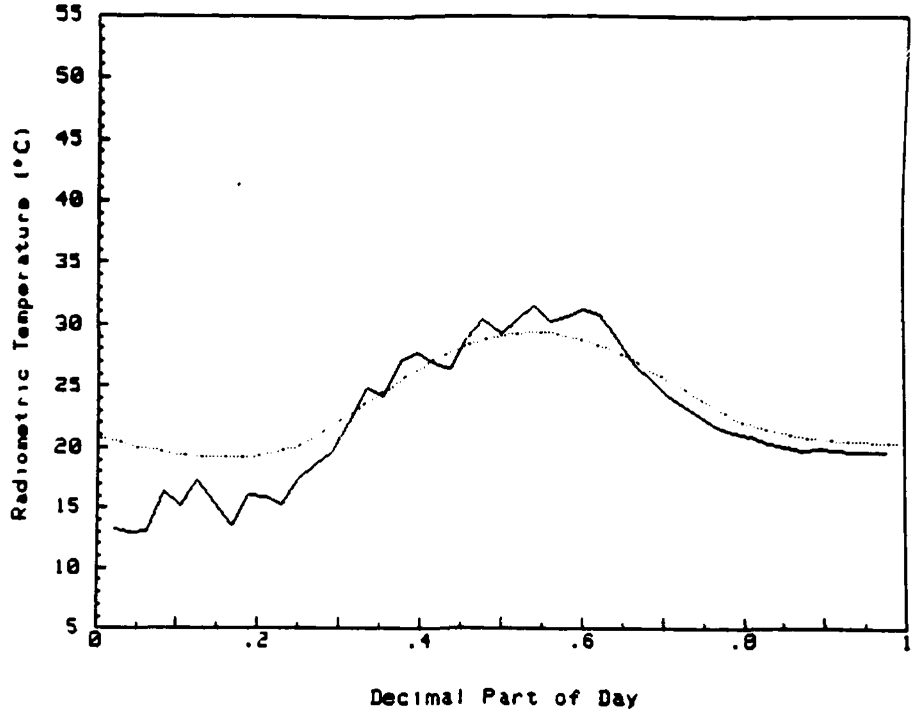

Figure 3. Measured (solid line) and predicted (dotted line) effective blackbody temperatures for bare soil on an overcast dry summer day on August 25, 1987.

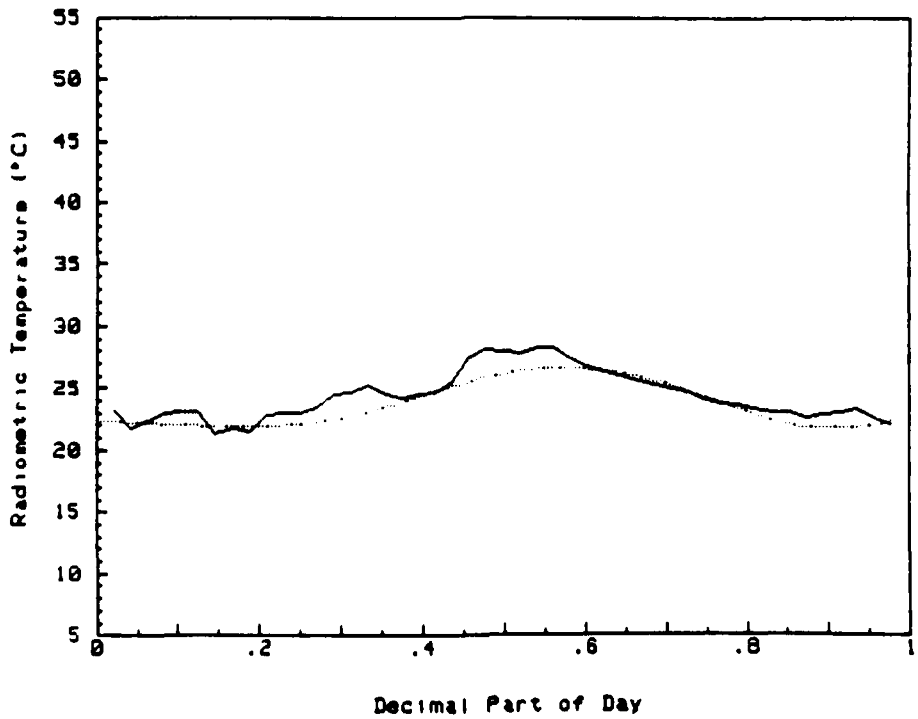

Figure 4. Measured (solid line) and predicted (dotted line) effective blackbody temperatures for bare soil on an overcast rainy summer day on August 22, 1987.

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